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Dynamics of Longitudinal and Transverse Modes Along the Junction Plane in GaAlAs Stripe Lasers

F. MENGEL AND V. OSTOICH

Abstract—Observations of the transient excitation of higher order transverse modes along the junction plane in DH GaAlAs stripe lasers during subnanosecond pulse modulation is reported. These modes are strongly excited at the onset of the light pulse, they decay during 200 ps, and reappear after 400–600 ps. The width of the longitudinal mode spectrum decays from 40 to 10 Å during 0.5–1 ns.

INTRODUCTION

This correspondence reports on the experimental investigations of the transient behavior of the fundamental and higher order transverse modes along the junction plane in DH GaAlAs stripe lasers which operate stably in the fundamental modes under dc conditions. The measurements were made both in pulsed operation, allowing the use of high current levels, and during continuous pseudorandom bit sequence (PRBS) modulation at 200 Mbits/s.

Recently, attention has been given to the influence of fast pulse modulation on the width of the longitudinal mode

spectrum [1], [2]. Experiments [2] have indicated that the spectral width during a pulse mainly is given by the spectrum at the start of the pulse, suggesting that the bias current should be sufficiently above threshold for only a few longitudinal modes to exist. The dynamic properties of the higher order transverse modes have received little attention so far, although this topic may be important for the coupling efficiency and pulse dispersion of a slightly overmoded glass fiber attached to the laser [3].

EXPERIMENTS

The lasers used in these experiments were commercial CW double heterostructure stripe geometry GaAlAs lasers with threshold currents in the range 190–250 mA¹ and with stripe widths close to 10 μm. The lasers were driven by an avalanche transistor pulse generator giving current pulses with a risetime of 200 ps and a halfwidth of 6 ns and an amplitude determined by fixed attenuators. These were superimposed on the end of a 30 μs bias pulse, where sufficient thermal stability is obtained. The time-resolved spectra were obtained using a 1 m spectrometer and an avalanche photodiode² coupled to a sampling oscilloscope. Part of the light was focused onto another avalanche photodiode placed in front of the spectrometer to monitor the total light output. The overall risetime of the detection system was estimated to be 220 ps.

Fig. 1 shows three spectra obtained at different times relative to the onset of the light pulse. The bias current was 112

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¹Laser Diode Laboratories LCW 10.

²Telefunken BPW 28.

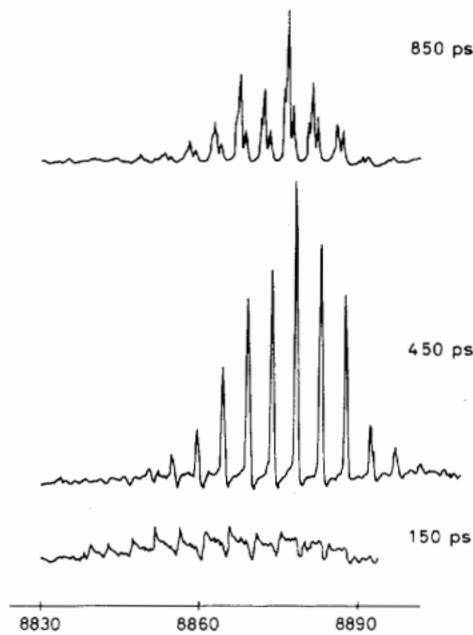


Fig. 1. Time-resolved spectra at different instants after the onset of a light pulse. Bias current 112 mA, pulse amplitude 200 mA, threshold current 112 mA.

mA, the pulse amplitude 200 mA, and the threshold current 198 mA. The usual relaxation oscillations of the light pulse are shown in Fig. 2(a), and the half power width of the longitudinal mode spectrum in Fig. 2(b). The width is seen to decay during approximately 1 ns to a stationary state corresponding to three longitudinal modes at a separation of 4.7 Å. This behavior is only weakly dependent on the bias and pulse currents over a wide range, although the decay generally becomes faster for increasing bias currents. Fig. 2(c) shows the distribution of light power in the transverse modes as deduced from the time-resolved spectra. It is seen that high-order transverse modes are excited in the start of the pulse. They decay during a few hundred picoseconds, leaving the laser in the fundamental modes, but reappear after 600 ps, dominating the laser emission completely. An unambiguous association of the spectrum with a particular transverse mode number is not possible in the start of the pulse, but in the spectrum at 850 ps the first- and second-order modes are clearly visible. The measured transition times between the regions of fundamental and higher order emission are limited by the response time of the detector. The transverse modes in the beginning of the pulse are generally excited more strongly the further below threshold the bias is chosen, but they appear even when biasing above threshold. The central wavelength of the envelope of the first-order modes is 10–5 Å lower than that of the fundamental modes, the difference decreasing with increasing bias current. After 0.5–1 ns, the high-order modes reappear, dependent mainly on the total peak current but not on the relative value of the pulse and bias currents.

The laser from Figs. 1 and 2 was also modulated with a PRBS signal at 200 Mbits/s superimposed on a dc bias to check the validity of the results under more realistic drive conditions. Fig. 3 shows a typical pulse train in a 2048 bit sequence at a bias below (a) and above threshold (b) with constant modulated power. The spectrum during the last pulse in Fig. 3(a) is shown in Fig. 4, and the transverse modes can again be seen in the beginning of the pulse. These modes reappear at the end of the pulse. The spectrum during the first pulse in the sequence, which is preceded by a zero, was

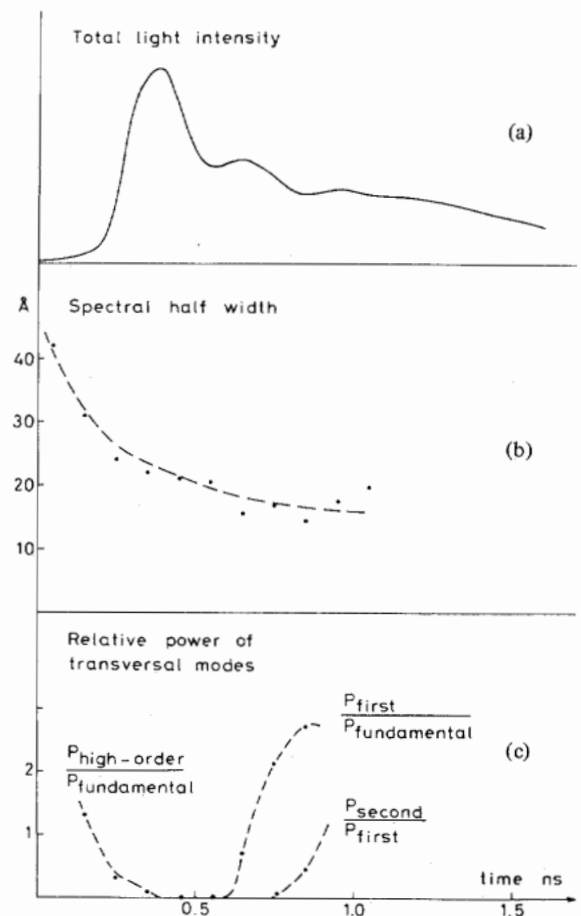


Fig. 2. Time evolution of laser emission in the pulse corresponding to Fig. 1. (a) Detected light pulse. (b) Half power width of the longitudinal mode spectrum. (c) Relative power in fundamental, first- and second-order transverse modes.

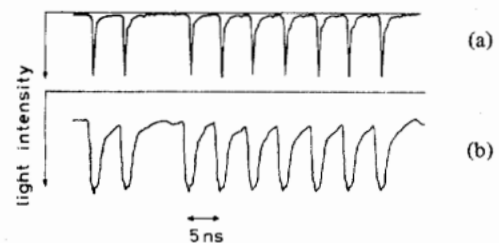


Fig. 3. PRBS modulation at 200 Mbits/s. Threshold current 212 mA, pulse amplitude ≈ 60 mA. (a) Bias current 181 mA. (b) Bias current 230 mA.

similar to the one shown except for the fact that the transverse modes do not reappear due to the absence of the prepumping effect, visible in the last pulse as a "bump" on the trailing edge. When biasing above threshold in (b), the transverse modes are strongly excited during the pulse, even though the bias is not sufficient to reduce the spectral width below 30 Å. No significant dependence of the central wavelength of the envelope of the laser spectrum in a pulse on the preceding pulse pattern was found in the two cases in Fig. 3.

A possible explanation of these observations can be found by combining the usual rate equations [4] with the equations describing the carrier density profiles along the junction plane [5], [6]. When the bias current is far below threshold, the spontaneous emission will dominate and excite all modes al-

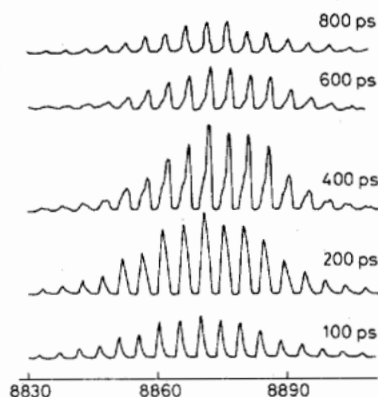


Fig. 4. Spectral evolution through the last pulse in Fig. 3(a) showing the presence of higher order transverse modes.

most equally. When a current pulse is applied, the electron density, and hence the gain in the part of the active layer located below the stripe contact, will grow, causing both fundamental and higher order transverse modes to be excited. Out-diffusion of carriers from the stripe edges will subsequently quench the first-order modes. The laser action in the fundamental modes will limit the electron density in the center of the stripe to a value close to the critical density [4], while the outer regions of the stripe will be pumped further, thus increasing the gain and hence the laser intensity in the first-order modes. The absolute behavior depends on the magnitudes of the electron and hole diffusion constants as well as the photon lifetimes for the various transverse modes.

Computer simulations [7] based on this model have yielded results in qualitative agreement with the observations.

CONCLUSION

When a semiconductor stripe laser is modulated with fast pulses, it has been found that higher order transverse modes are excited in the start of each pulse. If the peak current is sufficiently high, these modes will reappear later in the pulses, eventually overtaking the laser emission. This phenomena may decrease the coupling efficiency to an optical fiber and cause fiber modes to be excited other than those present when the laser operates in the fundamental transverse modes. Due to the fact that as many as six longitudinal modes exist at currents up to 10 percent above threshold for the type of lasers tested, the spectrum during the pulses at 200 Mbit/s modulation had a width of 30 Å even though the bias was chosen above threshold.

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Surface Roughness and Laser Damage Threshold

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ARTHUR H. GUENTHER

Abstract—The essential results of a carefully controlled experimental investigation of the effect of roughness on laser-induced surface damage thresholds in fused silica are reported. Sets of fused silica samples were subjected to several surface preparations such that rms surface roughness values within each set varied over two orders of magnitude. A plot of surface damage threshold versus surface roughness shows that there is a strong dependence of threshold on roughness, that this dependence exhibits a simple functional form, and that this relationship appears to hold even for the smoothest of optical surfaces. The utility of the observed threshold-roughness relationship is discussed.

Until recently, only a few experimental and theoretical observations have been made concerning the effects of surface roughness on laser-induced damage [1]–[4]. In 1975 [5], we presented the preliminary results of a series of carefully controlled experiments, using well-characterized samples, on the effects of surface topographic properties on laser-induced damage thresholds. We outline in this note the results of this surface roughness investigation.

Samples of fused silica were damage tested at 1.06 μm using TEM₀₀ pulses of 40.5-ns pulsewidth produced by a laser system described elsewhere [5]. These samples were prepared as follows: conventional polish using barnesite (denoted as CB); CB plus a short etch in dilute nitric acid; CB plus overcoat with a half-wave (at 1.06 μm) thickness of MgF₂ or SiO₂; and CB plus flame polish. Prior to polishing, all samples were control ground (see [5]) through a 3- μm grit stage to minimize the subsurface disorder produced by grinding. Various final values of surface roughness were achieved by stopping the polishing operation after appropriate periods. Surface roughness values were measured by the techniques of fringes of equal chromatic order (FECO), total integrated scattering (TIS), and Talystep stylus measurements. Damage thresholds were determined by irradiating a virgin site each time the laser was fired; and all sites on each sample were shielded from each other against plasma blowoff and any resulting optical plasma radiation.

Fig. 1 presents a log-log graphical summary of the data, the vertical axis being the macroscopic breakdown electric field¹ and the horizontal axis being the rms surface roughness. Bloembergen's 100-Å limit [3] is identified to show that most of the present data fall below that value. It should be noted that surfaces with rms roughnesses considerably less than 100 Å will usually still contain numerous surface asperities greater than the 100-Å Bloembergen limit. Fradin's value for the laser-induced bulk damage threshold of fused silica [4] has been plotted by assuming the bulk "roughness" to be equal to the average interatomic spacing. Each data set has been best-fitted with a straight line, the equation of which is

$$E \sigma^m = \text{constant.}$$

Except for the flame polished samples, the value for m centers around 0.5 for all the surface treatments. For the flame

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¹This electric field is the effective field at breakdown, produced in the surface of the material by the laser beam. It is termed macroscopic because it is the resultant, total electric field satisfying the boundary conditions (i.e., the Fresnel transmission relationship).